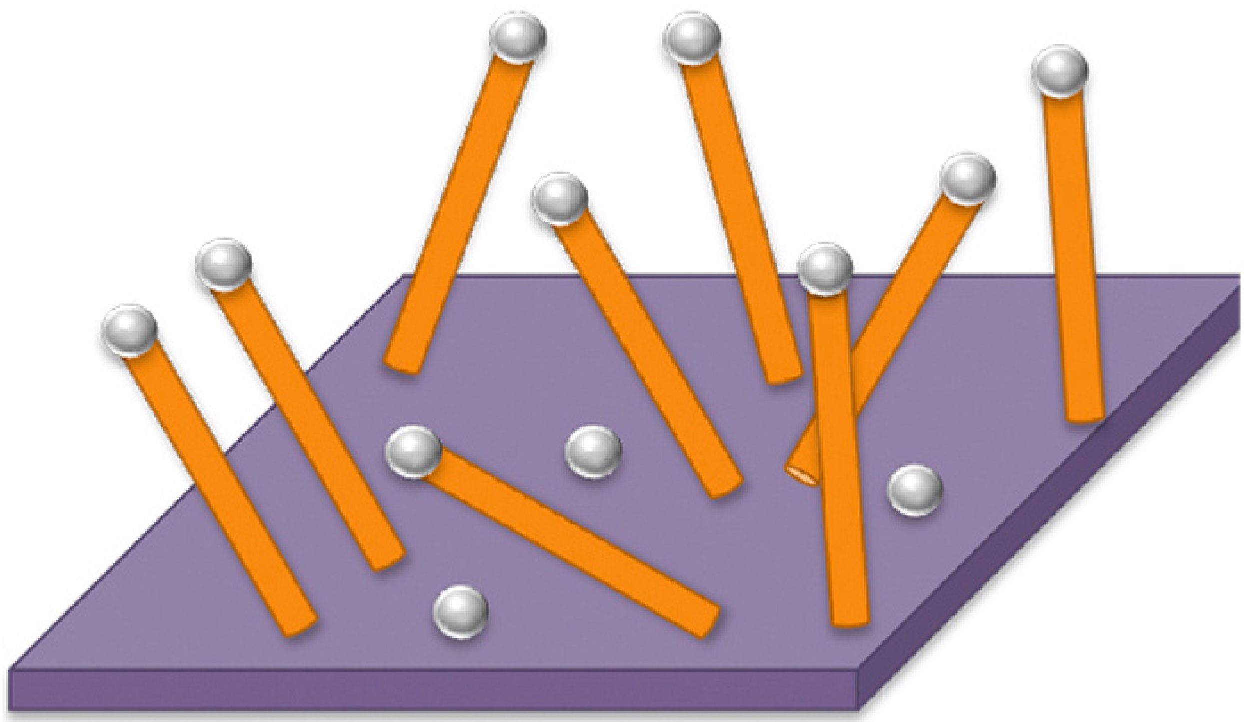
Gaining creative control over semiconductor nanowires

September 26, 2013



A Los Alamos research team has transformed the synthesis process of semiconductor nanowires for use in solar cells, batteries, electronics, sensors and photonics using a solution-liquid-solid (SLS) batch approach to achieve unprecedented control over growth rates, nanowire size and internal compositional structure.

The high cost of industrial scale manufacturing of semiconductor nanowires presents a significant barrier. Solution-liquid-solid batch synthesis of these nanowires is a lower-energy and potentially more cost-effective approach compared with many vapor-phase methods due to its compatibility with technologically desirable flexible, temperature-sensitive substrates and simple solution-phase processing techniques. However, insufficient synthetic control over the nanowires hampers this method. The journal *Nature Nanotechnology* published the research.

Significance of the research

The conventional SLS technique entails the injection of chemical precursors into a hot surfactant solution in a flask. Molten metal nanoparticles catalyze the nucleation and elongation of single crystalline nanowires. Because of the rapid nanowire growth and the inherent limitations of flask-based chemistry, changes in composition along the length of the nanowires to fabricate superlattice-structured nanowires are largely precluded in SLS.

Using a microfluidic reactor, Los Alamos researchers transformed the SLS process into a flow-based technique. The new “flow” solution-liquid-solid method allows scientists to slow down growth and thereby capture mechanistic details as the nanowires grow in solution. The new mechanistic insights enable researchers to predict which synthetic variables can be used as “knobs” to tune nanowire structure.

Using this knowledge, the team demonstrated control over nanowire diameter down to ultrasmall sizes below 10 nanometers. They also fabricated technologically relevant axially graded semiconductor nanowires. The new method is a versatile platform for studying nanowire growth processes toward a ”designed” materials strategy. It’s also an important step toward a practical solution-phase alternative to more costly gas-phase techniques for fabricating complex bandgap-engineered and heterostructured nanowires. Once removed from their substrates, the nanowires can be easily fashioned into composite structures or integrated into devices.

Research achievements

The Laboratory researchers transformed the SLS synthesis into a continuous technique, called flow-based SLS, in a microfluidic reactor. In general, microfluidic systems offer the advantage of improved control over growth conditions. For the first time, the scientists adapted such a system to accommodate growth from a solid substrate. To achieve this functionality, the researchers designed a novel resealable microfluidics “chip” that holds in place a substrate containing nanoparticle catalysts. A carrier solvent flows in reactants and coordinating ligands. Reaction by-products are transported away from the growing nanowires and out of the reactor.

The scientists utilized this new method to form nanowires from cadmium selenide (CdSe) and zinc selenide (ZnSe) as well as CdSe-ZnSe superlattice structures. As in conventional SLS, the team regulated nanowire length and diameter by manipulating the size of nanoparticle catalysts, reaction temperature, and time. They uniquely demonstrated that two different processes govern the solution-phase growth and used this knowledge to devise unexpected conditions to control the minimum achievable nanowire diameter.

The research team

Researchers include former Director’s Funded postdoc Rawiwan Laocharoensuk (now with Thailand’s National Science and Technology Development Agency), Kumaranand Palaniappan, Nickolaus Smith, Jon Baldwin and Jennifer Hollingsworth of LANL's Center for Integrated Nanotechnologies; Robert Dickerson of Materials Technology-Metallurgy; and Donald Werder (formerly of Physical Chemistry and Applied Spectroscopy (C-PCS), now with Cornell University).

This work was performed in large part at the Center for Integrated Nanotechnologies (CINT), a DOE Office of Science Nanoscale Science Research Center and User Facility. The Los Alamos portion was sponsored by CINT, a Director’s Postdoctoral Fellowship, CINT postdoctoral funding and the Laboratory Directed Research and

Development (LDRD) program. The research supports the Lab's Energy Security and Global Security mission areas and the Materials for the Future science pillar.

Captions for images below: Flow chip mounted in a holder. / Scanning electron microscopy image of ZnSe nanowire grown in the flow-SLS system.

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